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THE REFLECTION OF LOW FREQUENCY SONAR SIGNALS FROM A SMOOTH OCE--ETC(U)
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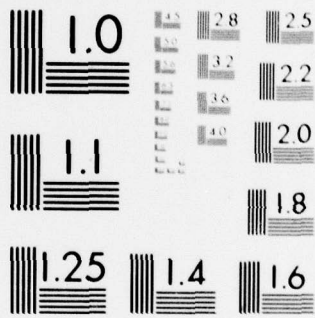
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THE REFLECTION OF LOW FREQUENCY SONAR SIGNALS
FROM A SMOOTH OCEAN BOTTOM.

Part I'

Experimental Reflection Losses at Locations off
the California Coast and in the Bering Sea,

by

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ABSTRACT

Underwater acoustic tests in three different areas are discussed: Area I is in 200-fathom water while Areas II and III are deep-water, 2000-fathom areas. From the data obtained bottom reflection losses were computed as a function of grazing angle for low frequency, 0.7 to 3.0 kc sound pulses. Measurements in Area I utilized short pulses and acoustic-path geometries that would resolve the bottom reflected paths; the analysis was then accomplished by comparing the direct signal with the signal which suffers one bottom reflection. The experiments in the deep-water areas did not attempt acoustic path resolution and the bottom loss was derived from the difference between the measured propagation loss and the theoretical propagation loss for that range and for total reflection at that grazing angle.

Results from Area I show considerably more scatter than the bottom losses in Areas II and III. The bottom losses observed in Area III were appreciably less than those found in other deep sea areas. Maximum losses in Areas II and III occurred at grazing angles 14° to 20° with peak losses of about 10 db in Area III and 20 db in Area II at 1.3 kc. Bottom losses in the shallow Area I were maximum between 45° and 55° with losses of 12 to 14 db (similar in magnitude to Area II losses at those angles). Also, a secondary maximum of about 10 db occurs at 24° in Area I.

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Part I
Experimental Reflection Losses at Locations off
the California Coast and in the Bering Sea

Introduction

Studies of the effects of the ocean bottom on the propagation of underwater sound are often of prime importance in the understanding of sonar propagation. In many areas the sea floor has a predominant influence. In shallow water areas--for example--propagation to long range is accomplished by repeated surface and bottom reflections. In deep water, propagation via a bottom reflection may be of considerable interest. In order that sonar equipments be improved both in their design and use, a greater understanding of the influence of the sea floor is needed.

To fill this need, bottom reflection studies¹⁻⁶ have been and are at present being conducted. This report will give the results of sea tests conducted in three different test areas. In Part II of this paper theoretical curves will be fitted to the experimental results. Calculations based on stratified models of the ocean bottom are performed using physical constants that correspond to these areas^{7, 8}.

Acoustic Tests

A. Areas of Operation

Sea tests were conducted in two deep-water (2000-fathom) areas and in one 200-fathom area. These test sites were located in the Bering Sea and off the coast of California. For the purposes of this paper the 200-fathom area shall be designated Area I, while the deep-water sites shall be called Area II and Area III. These areas will be more completely described in other sections of this paper.

The method of measurement used in Area I differed in part from that employed in the deep-water areas. Short pulses, variable source and receiver depths, and relatively stable geometries were used in the 200-fathom area and resolution of all possible acoustic paths was generally achieved. In the deep-water areas relatively shallow, omni-directional transducers and half-second pulses were used and a four-path* analysis of the data was employed. At this point it will be convenient to separate the discussion of the measurements and analysis into these two parts.

*Each bottom reflected path is four-fold: Source-Bottom-Receiver, Source-Surface-B-R, Source-B-S-R, and Source-S-B-S-R.

B. Experimental Measurements: 200-Fathom Water

A series of experiments⁹ were conducted in 200-fathom water off the coast of California, beginning in October 1961 and ending in June 1963. Two ships were employed and two types of tests were utilized. In the first set of tests, one ship was anchored and the other was allowed to drift away. The transducers were at a constant depth and the angle varied as the ships opened range. In the second set of tests, both ships were anchored and the angle was varied by varying the depth of the transducers. Both ships employed similar electronic equipment and transducers to generate and transmit seven-millisecond pulses at 1.5 kc.

According to E. L. Hamilton, Area I is a transition area for the upper few feet of sediment, changing from patched regions of silty sand and sandy silt near the shore to silt in deeper waters. In general, there is a fine-grained sediment at the surface which grades to coarser material at depths between a few inches to one and one-half to two feet. Because of the nearness of this area to shore and the lowered sea levels of the Pleistocene epoch, changes from silt-to-sand and sand-to-silt and the presence of sand lenses in the sediment body may be expected. The results of an analysis of one of the core samples taken in this area is shown in Table 1 (see also reference 10). These values are from an unpublished study by E. L. Hamilton and may be considered typical of the area. In brief, the

bottom may be characterized as a flat area of sandy silt approximately 20 feet thick overlying rock (shale or sandstone). The silty layer has a sound speed--at the surface--lower than that of the bottom water, but a large velocity gradient exists within this layer. The underlying rock has a high sound speed and density. See Table 1 and references 10 and 11.

TABLE 1
Physical Properties of the Bottom

LAYER	SOUND SPEED m/sec	DENSITY gm/cm ³
Bottom water	1489	1.03
Silt layer:		
Surface	1460	1.65
50-60 cm	1564	1.78
150-160 cm	1533	1.72
300-310 cm	1638	1.87

The geometry for the first set of tests was computed separately for each pulse. The transducers were at 900-1000 feet and at this depth the effects of refraction were negligible. The geometry for the second set was computed for each group of 20 pulses. The transducers were either deep enough to avoid refraction effects or the angles were high enough so that there were negligible refraction effects in all Area I experiments.

Two omnidirectional receiving hydrophones were suspended from each ship at 50 and 300 feet for the first set and 100 and 500 feet for the second set of tests. In both sets of tests the transducers were used

as receivers also. A radio pulse was transmitted in synchronization with the acoustic pulse in order to obtain the travel time and range. The acoustic signals, the radio pulse, and time marks were recorded on a Honeywell Visicorder on direct-print linagraph paper. Velocimeter lowerings were made to the bottom and these data were augmented by 900-ft BT's taken at various times during the tests.

C. Data Analysis: 200-Fathom Water

Bottom losses were calculated from the ratio of the observed pressure of the bottom reflected signal to that of the direct signal. Corrections to the observed pressures because of the difference in path of these two arrivals were made assuming straight line propagation and spherical spreading. Because of the short ranges and the use of deep sources it was generally possible to resolve the four paths having one bottom reflection. The results reported here concern only the source-bottom-receiver path.

The bottom loss was computed as minus 20 times the log (base 10) of the ratio of the bottom reflected signal to the direct-arrival signal, and corrected for transducer directivity and difference in path length. Comparison of results using this method with those obtained by reducing the received bottom reflected pulse to a pressure level referred to one microbar at one yard, and subtracting the source level, showed no significant difference. This latter method was used only when the direct signal and the surface reflected signal were not resolved.

D. Experimental Measurements: 2000-Fathom Water

The tests in the two deep-water areas were very similar. Much of the same equipment was used and the source and receiving transducers were of the same type. Sources were towed at approximately 50-ft depth at about five knots. Each transmission run began with a close approach to within 300 yards of the receiving ship and the range was opened to 30-35 miles over fairly flat, deep-sea clay (Area III) and silty-clay (Area II) bottoms.

CW pulses of half-second duration were transmitted at frequencies of 0.7 and 1.3 kc (plus 3.0 kc in Area II) and received at three omnidirectional hydrophones suspended from a buoy well away from the receiving ship. Receiver depths of 50, 250, and 300 feet in Area II and 50, 250, and 500 feet in Area III were used. Radio pulses were transmitted in synchronization with the acoustic pulse to provide travel-time information. The received signals were recorded, broad band on magnetic tape, and later played back through filters to separate the data.

Temperature and salinity data were recorded and later used to compute velocity-depth profiles. Sea states of one or two were observed.

E. Data Analysis: 2000-Fathom Water

The analysis of these data was based on the calculations of the propagation loss from the depth-velocity profile. The excess in the total measured propagation loss above the theoretical propagation loss

is the bottom loss for that range and grazing angle. The db loss per bottom reflection as a function of grazing angle was then obtained. First and second bottom reflections are included in the Area II data while in Area III, three or more bottoms were observed and the first, second, and third reflections were used in this analysis.

The amplitudes of the direct and the first, second, and third reflected arrivals were reduced to signal levels referenced to one microbar. Signal levels were then subtracted from the appropriate source level to determine the total propagation loss. The difference between this figure and the theoretical loss due to the water medium was assigned to bottom loss. The db loss per reflection was obtained by dividing by the order of the reflection.

Calibrated source levels were checked by comparison of the directly received signal levels and those calculated from the theoretical interference pattern between direct and surface-reflected acoustic paths¹² (i.e. the Lloyd mirror effect). Small corrections not greater than 3 db for source directivity and/or noise (whenever the signal-to-noise ratio was low) were made in some of the data. Source levels were further verified by comparison of the first and second bottom reflection losses whenever applicable.

Values of the bottom loss were obtained by subtracting the measured sound intensity (in db) of the bottom reflected signal from the theoretical intensity that would result if the bottom loss were zero. The theoretical calculations were made using computer programs developed at NEL by M. A. Pedersen¹³ and D. F. Gordon. In these ray intensity calculations

the sound velocity profile is represented by a smooth curve which is adjusted to fit the experimental velocity-versus-depth values. An exact solution of the ray spreading was made for those paths which travel from the source to the receiver and a correction added to account for the absorption of the sound in water. At the ranges involved, less than 40 kys for one bottom reflection, these corrections for absorption were less than 2 db except at 3.0 kc for some of the greater ranges. The intensities of the four rays that have had one reflection (those rays traveling upward and downward at the source and receiver) were added to give the expected intensity, assuming no bottom loss of the single bottom reflected signal.

Horizontal ranges as a function of travel time were obtained from the computer calculations and were used to transform delay times to horizontal ranges. Grazing angles versus horizontal ranges were also obtained from the ray calculations and each bottom loss was assigned a grazing angle. Individual bottom losses were classified into two-degree intervals and averages and standard deviations were found for each interval.

Results and Discussion

In Area I the results from the two ships and the results from the three receivers showed no significant differences. Therefore, the bottom loss results expressed in db from all tests and all receivers were averaged together in two-degree intervals and are presented in Fig. 1. The standard deviations were computed for each interval, and the vertical lines in Fig. 1 indicate values of the bottom loss within \pm one standard

deviation. Standard errors of the mean losses were computed and were less than 2 db for all intervals but those at 38, 50, 58, and 64 degrees.

The multiple peaks in bottom loss seen in Fig. 1 can probably be attributed to interference effects from sound reflected from the water-silt interface with either sound reflected back from the silt-rock interface or possibly from sound reflected back into the water by irregular layering in the silt layer.

In Areas II and III the results for the different receivers, also, showed no dependence upon hydrophone depth. Thus the data from the different receivers were averaged together. Further, the average losses for different orders of reflection at the same grazing angle were nearly equal. In Fig. 2 the average loss per bottom reflection is shown for 1.3 kc pulses in Area III. Only in a few instances--at 18° and 30° (first bottom reflection compared to third), and at 22° and 74° (second compared to third bottom reflection)--are there apparent differences between mean values at the same grazing angle. Among the data from Areas II and III none of the differences between mean values at the same angle were found to be statistically significant at the 98 percent level. Only those instances mentioned above, from Fig. 2 and one other mean difference could be considered significant at the 95 percent level of confidence (that is, the probability of a difference as large as observed having occurred due to chance sampling, rather than representing a real difference, is only 0.05, or less). This statistical consistency of reflection losses determined along different acoustic paths can be considered a valid check of the methods used to remove spreading loss and attenuation in the water

medium from the final result sought. Since reflections of different orders gave statistically similar results for loss versus grazing angle, all orders were included and the final results from these two deep-water areas are presented, Fig. 3 and 4, in composite averages of bottom loss, expressed in db, per bottom reflection for grazing angles centered at two-degree intervals. Standard errors (i.e., the standard deviation divided by the square root of the number of observations) of the mean losses were computed and found to be--in almost all instances--less than one decibel. In Fig. 3 and 4 the average number of observations per point is 27; and 90 percent of the plotted points are the averages of 13 or more observations.

The most notable feature of the data in Figs. 3 and 4 is the shape of the data curves in exhibiting high losses below 22° . In Area III (Fig. 4) these are peak losses at $16-18^{\circ}$. Although the data from Area II below 22° are limited for 0.7 and 3.0 kc (inadequate source power), the trend toward higher losses is clearly shown at 3.0 kc. The 1.3 kc data show maximum losses of 20 db at about 14° in Area II and about 10 db at 16° in Area III. Below 14° the losses show a downward trend with decreasing grazing angle.

The bottom losses observed in Area I show considerable more scatter than the bottom losses from the two deep-water areas. (Note that the figures have different ordinate scales.) At 1.3 kc and for two-degree intervals the average standard deviation in Area II is 2.4 db and in

Area I (1.5 kc) the standard deviation averages 4.4 db. Also in Area I (see Fig. 1) the fluctuation between adjacent averages is quite large. In Part II of this paper the fluctuation of these data will be discussed in more detail.

The shape of the data curves in Figs. 3 and 4 differs from that of Area I (Fig. 1) and that of other investigations such as Mackenzie's¹¹ (1.0 kc and 125 and 600 fathoms), where the reflection loss tends toward zero for grazing angles less than critical, and that reported by T. G. Bell³ and H. W. Marsh⁴.

The bottom losses at 1.3 and 0.7 kc from Area II were several decibels higher than those observed in Area III for most grazing angles with the exception of 22-26° where the Area II graph dips down to low losses only slightly greater than Area III losses. Probably in Area II there is a highly reflecting subbottom, while in Area III the top layer(s) of sediment are more absorbent to sound at these frequencies and extend relatively deeper. The losses at the higher grazing angles are thus highest in Area II. The higher frequencies show the highest losses as expected; the 1.3 kc losses are consistently the greater in Area III, while the highest losses are at 3.0 kc in Area II. However, in Area II the 0.7 kc losses are at times greater than those at 1.3 kc.

Conclusion

Although the graph drawn through the average losses found in the 200-fathom area differs greatly from the data curves from the deep-water areas, the purpose of this paper is not to attempt to correlate water depth and bottom loss. This division was fortuitous not only in our choice of areas but also in the method of the measurements. The methods used in these deep-water areas are inclined more toward the method of operational sonars than those measurements of Area I.

Both curve shapes have been observed in deep and moderately deep water areas^{2, 14}. The differences in the bottom losses at the same grazing angle is believed to be quite dependent on the type and depth of sediment and layers of sediment. For instance, the sea floor in Area III probably has a shallow covering of absorbing sediment over a hard subbottom.

The second part of this paper will attempt to fit the above experimental data to theoretical computations based on physical models of the bottom.

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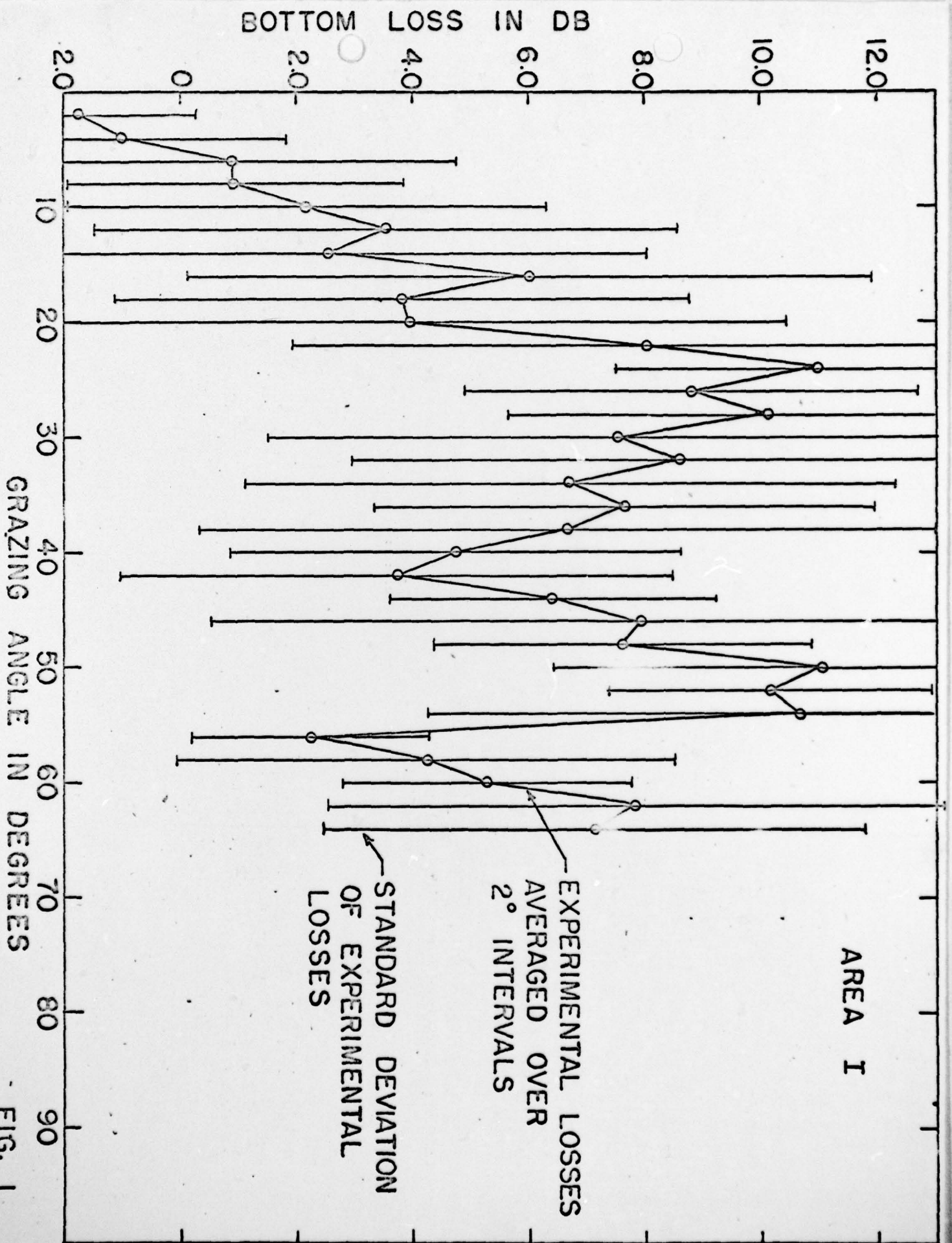
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1. Bottom reflection loss in the 200-fathom Area I, frequency 1.5 kc
2. Bottom reflection loss for the first three orders of reflection,
2000-fathom Area III, frequency 1.3 kc
3. Average bottom reflection losses observed in the deep-water Area II
for frequencies of 0.7, 1.3 and 3.0 kc
4. Composite average bottom losses observed in the deep-water Area III
at frequencies of 0.7 and 1.3 kc

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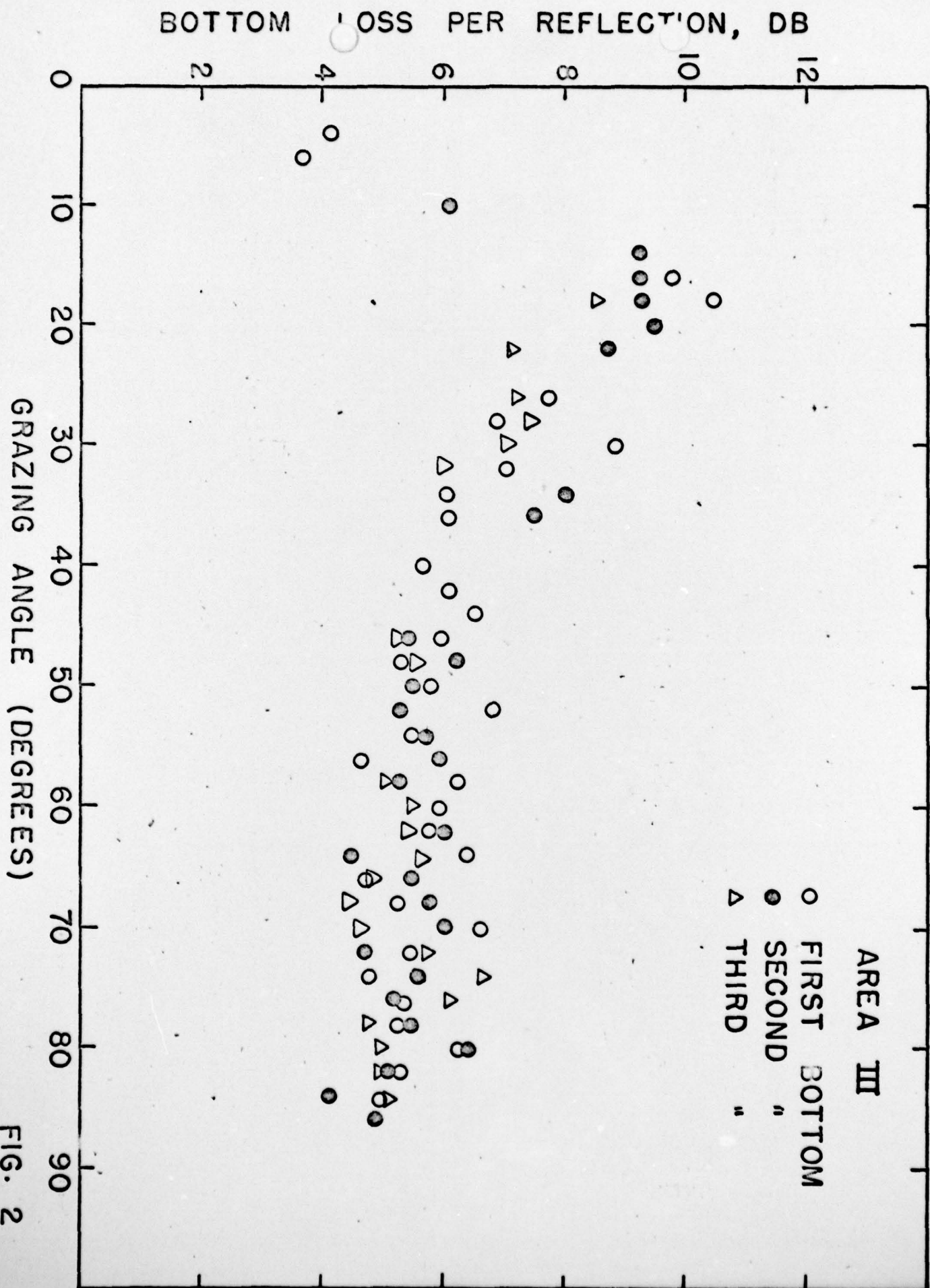


FIG. 2

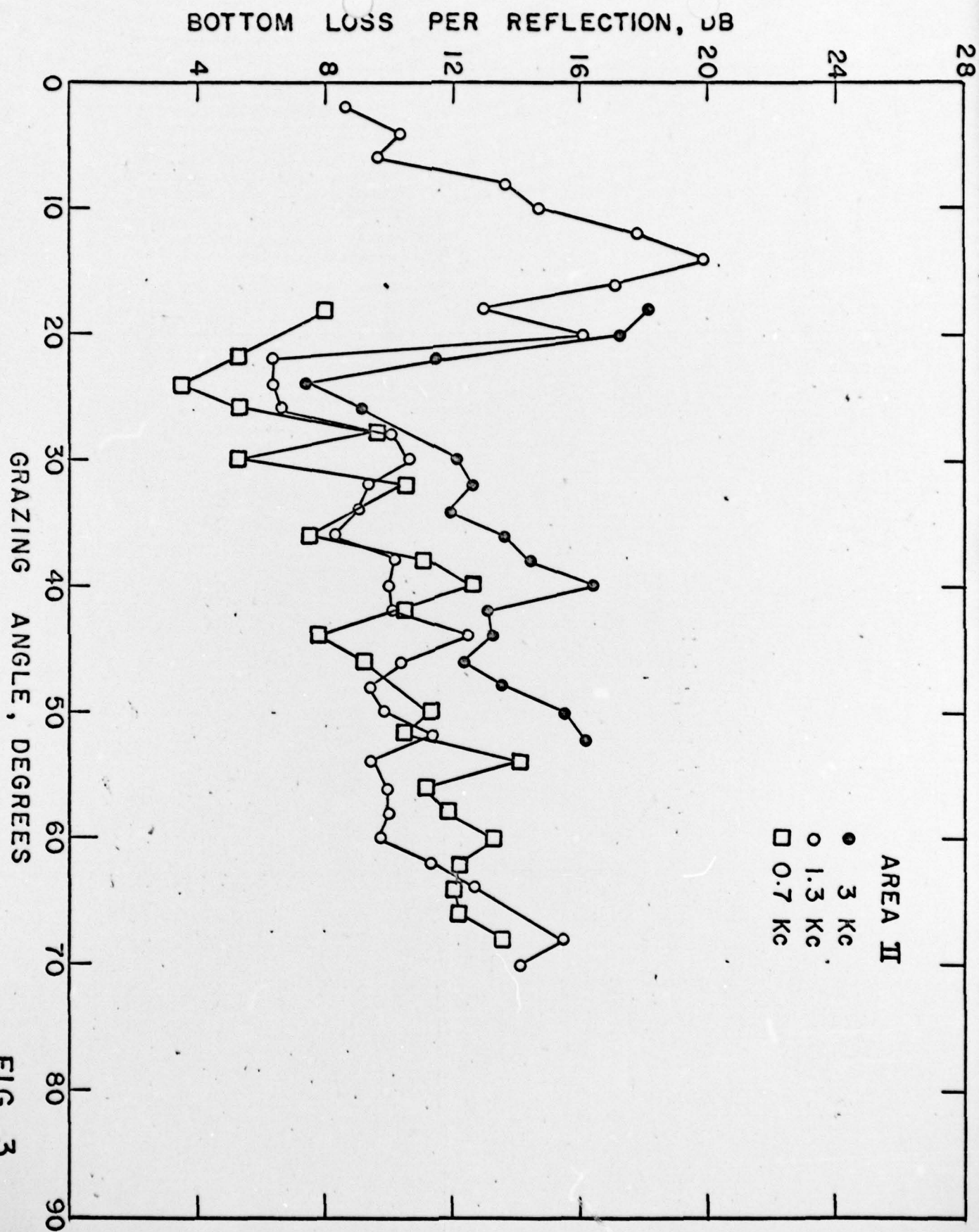


FIG. 3

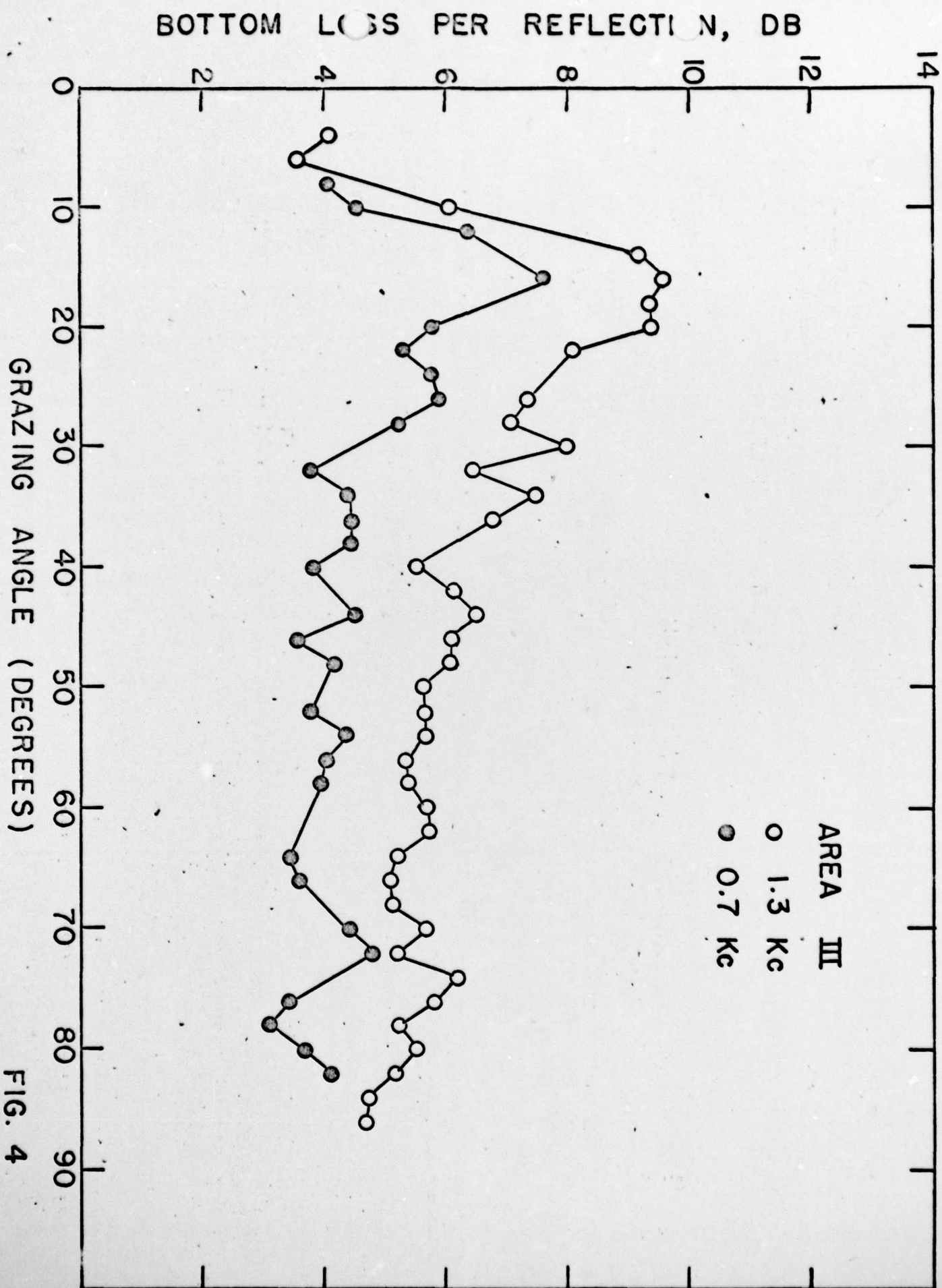


FIG. 4